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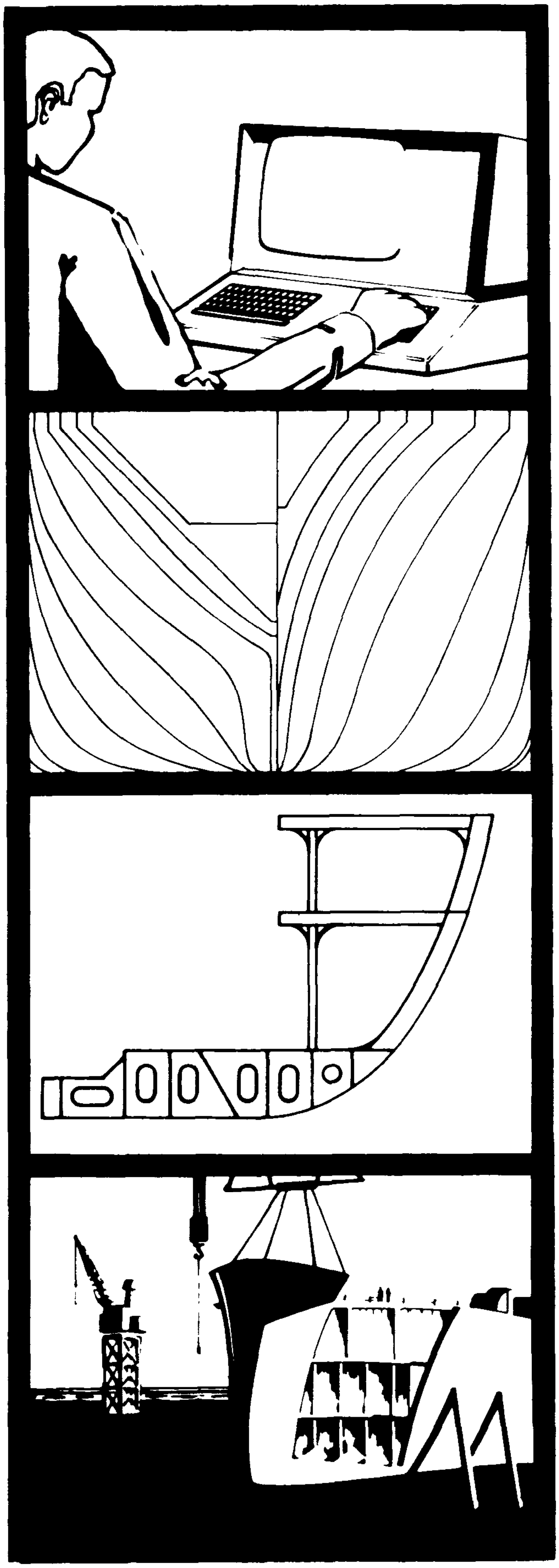

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FITNESS FOR PURPOSE:
A NEW LOOK AT WELD DEFECT ACCEPTANCE CRITERIA

Leslie W. Sandor
Manager, National Shipbuilding Research Program
Sun Ship Inc
Chester, Pennsylvania

Dr. Sandor is currently responsible for research programs to improve welding technology in the U.S. shipbuilding industry. He is also a Professor of Materials Science at Widener University in Chester, Pennsylvania.

Dr. Sandor has attended schools in Hungary, England, and the United States, and holds a doctorate in metallurgical science. His experience is research oriented, but interspersed with production and academic environments.

ABSTRACT

This presentation highlights the results of the "Weld Defect Tolerance Study" published under the Ship Producibility Program in June 1980. It is shown that the repair of innocuous defects currently adds $0.5 million to $1.0 million per ship in unnecessary cost, and that the end result in many cases may be even more deleterious to the completed structure. An update is provided on action being taken in the industry to improve/develop more rational acceptance standards for certain defects.

This paper describes the more important points of a project entitled "Weld Defect Tolerance Study". The basic thrust of understanding the real significance of weld defects is to decrease the cost of welded constructions through eliminating unneccesary repair of harmless weld discontinuites.

The focal point of the first phase of the study was commercial ship hull welds. Subsequently, and in response to shipbuilding industry recommendations arising from results of Phase I, a similar study is now underway on naval surface ships constructed from mild steel. It, was found that the repair of innocuous discontinuities consisting primarily of porosity and slag inclusions adds $0.5 million to $1.0 million per ship in superfluous cost and the quality of the end product in many cases is even more deleterious to the integrity of the structure than had the harmless defect been left in the weldment unrepaired.

When failure in commercial ship hulls occurs., fatigue was found to be the dominant failure mode caused primarily by inferior design details and unsatisfactory joint fit ups or misalignments. Several other non-weld related causes were reported in the published literature. This suggests that existing weld acceptance standards are overly conservative. A survey of national and international publications on weld defects and an analysis of quality control data obtained from major U.S. shipyards show clearly the need to establish more rational weld acceptance standards than the current, workmanship-type standards.

Collection of data and information that reflect the actual events of manufacturing processes and systematic monitoring of the performance of ships are essential to the generation of rational weld acceptance standards formulated from statistical approaches and fracture mechanics principles- of relevance with respect to failure mode.

Since failures in sea-going vessels may be induced by many different causes, the introduction of the "Quality Control Systems Loop" Seems to be a logical approach to ship hull construction and a cost effective use of resources. Fitness-for-service, QCSL - an integral part of which is NDT - compliment one another for several reasons. Perhaps the single most important reason is that they are destined by definition to improve quality at the lowest possible cost. The fitness-for-service, QCSL, as well as NDT, require an orderly development and their full coordination in order to maximize their effectiveness. The rudimental tenets of fitness-for-service (purpose) and QCSL are good understandings of, and earnest appreciations for everything that takes place in the total system. The total system is not merely confined to what happens within the shipyard, but also includes in-service performance of the product of the specific shipyard. In other words, it is very important for everyone to know what takes place in the yard as well as at sea so that cause-and-effect relationships may be well established. Fitness-for-service and QCSL coupled together are bound to drastically decrease "quess work". Examples of Fitness-for-Purpose standards for slag and porosity, and of QCSL are shown in Fig. 1-2.

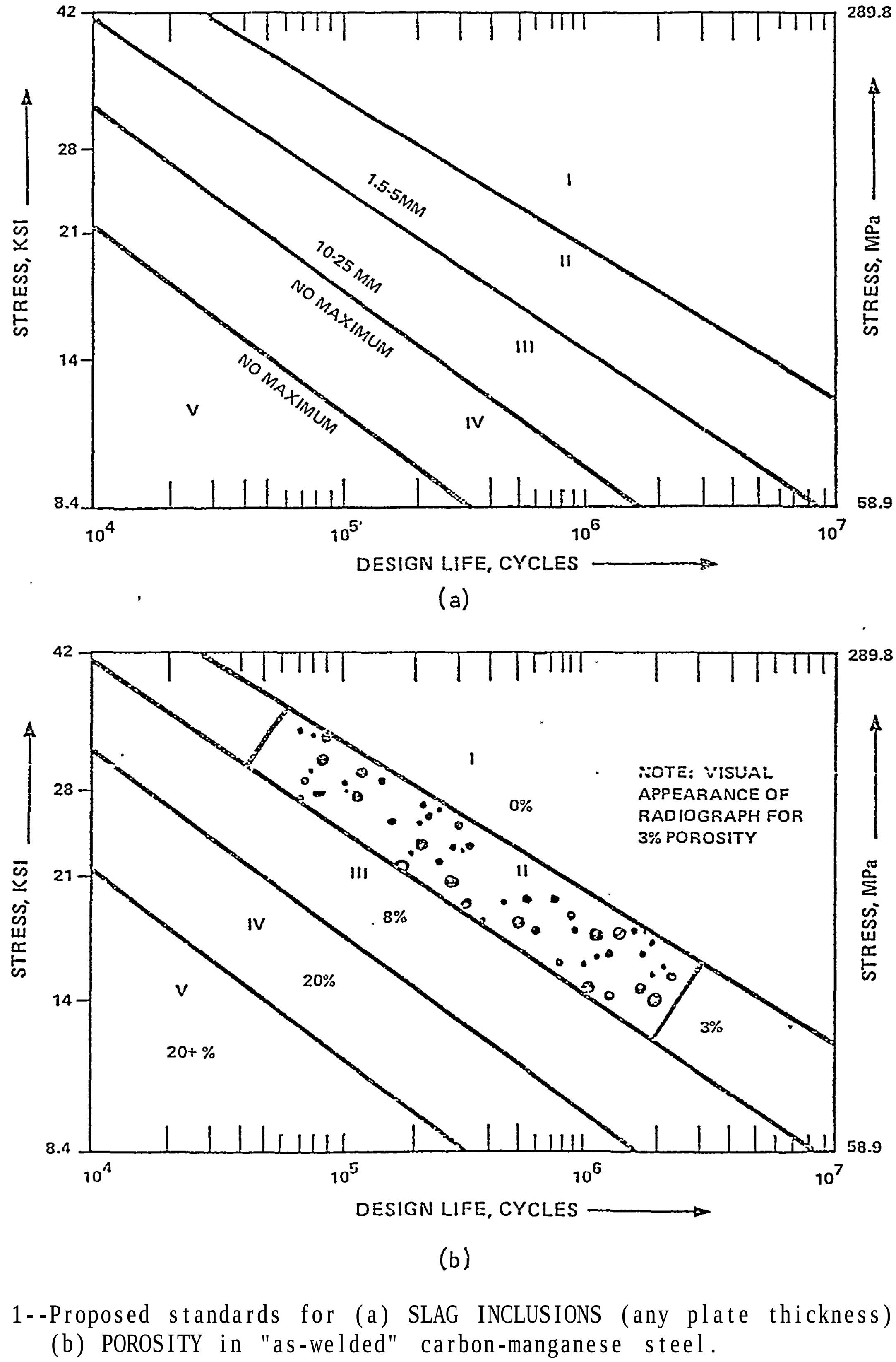


FIGURE 1--Proposed standards for (a) SLAG INCLUSIONS (any plate thickness) and (b) POROSITY in "as-welded" carbon-manganese steel.

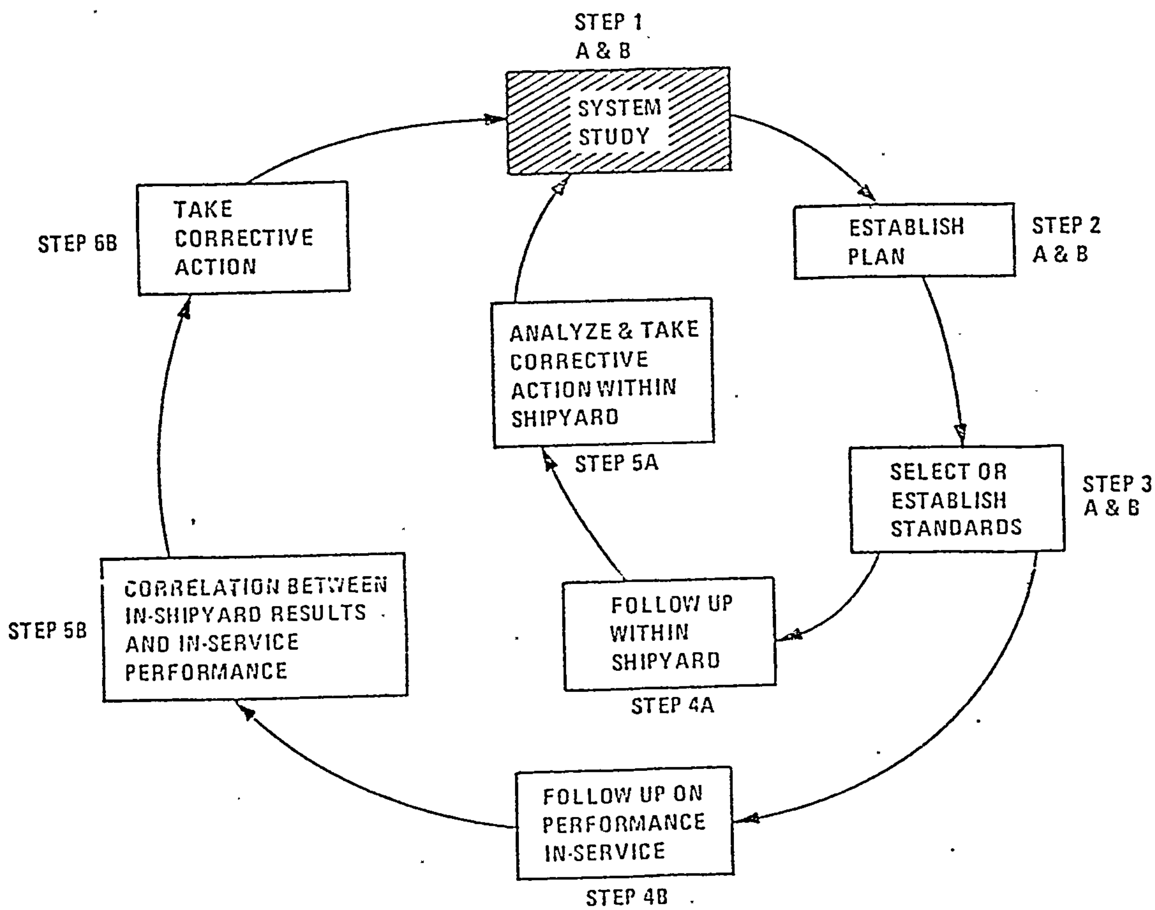


FIGURE 2--A schematic diagram of QCSL. Loop "A" represents in-shipyard scenario for short-range benefits. Loop "B" encompasses in-shipyard and in-service performance yielding long-range gains.

More specific details of Phase I study are given in the following captioned slides.

1. <u>WHY STUDY WELD DISCONTINUITIES</u>

(A) INTRODUCTION OF DEFECTS INTO WELDS IS UNAVOIDABLE,

(B) NOT ALL DEFECTS ARE HARMFUL,

(c) REPAIRING INNOCUOUS DEFECTS ENTAILS UNNECESSARY COSTS,

II, <u>WHAT IS THE REAL PURPOSE OF WELD DEFECT TOLERANCE</u>?

(A) OUTLINING OF CONDITIONS FOR AVOIDING SUPERFLUOUS WELD REPAIR COSTS AND WELDMENT DEGRADATION IN GENERAL AND NOT LOWERING OF PRODUCT QUALITY,

(B) "A FITNESS FOR PURPOSE" PHILOSOPHY,

III. WHAT KINDS OF WFLD DEFECTS ARE THERE?

(A) CRACK OR CRACK-LIKE DISCONTINUITIES.

(B) POROSITY, SLAG INCLUSIONS,

(C) LOF, LOP,

(D) GEOMETRIC DISCONTINUITY,

ANOTHER CATEGORIZATION:

(A) PLANAR,

(B) NON-PLANAR,

CATEGORIZATION BY LOCATION:

(A) SURFACE,

(B) BURIED,

(c) THROUGH-THICKNESS,

IV, <u>WHAT FACTORS DETERMINE THE SIGNIFICANCE OF THE DEFECTS</u>?

- TYPE
- SIZE
- SHAPE
- AMOUNT
- DISTRIBUTION
- ORIENTATION
- LOCATION

OF DEFECT

V. <u>WHAT ELSE IS NEEDED FOR ASSESSING WELD DEFECTS</u>?

1. PRINCIPAL STRESSES,
2. ENVIRONMENTAL PARAMETERS,
3. DESIGN CONDITIONS','
4. MANUFACTURING CONDITIONS,

VI. <u>WHAT IS THE BASIC DIFFERENCE BETWEEN PRESENT AND PENDING CODES EXPECTED FROM WELD DEFECT STUDIES</u>?

(A) PRESENT CODES:

- HISTORICAL
- OVERCONSERVATIVE
- UNNECESSARY REPAIRS
- ASSIMILATION OF MANY CODES,
- LACK OF INTERACTION EFFECTS,

(B) PENDING CODES:

- BASED ON **FR.** M.
- ELIMINATION OF SUPERFLUOUS WELD REPAIRS
- TAILORED TO SPECIFIC INDUSTRY,

VII. UNDESIRABLE CONSEQUENCES OF WELD REPAIR

- INCREASED RESIDUAL STRESS,
- INTRODUCTION OF NEW DEFECTS,
- MICROSTRUCTURE DEGRADATION,
- AGGRAVATION OR EXTENSION OF PRE-EXISTING DEFECTS UNDETECTED DURING ORIGINAL INSPECTION,
- ADDITIONAL WELDING PERSONNEL REQUIREMENT,

WELD REPAIR DOES NOT SIGNIFY AN IPSO FACTO IMPROVEMENT,

VIII, WHAT ARE THE PRINCIPAL FAILURE MODES?

- BRITTLE FRACTURE
- FATIGUE
- GENERAL YIELD
- LEAKAGE
- CORROSION, STRESS CORROSION FATIGUE
- INSTABILITY (BUCKLING)
- CREEP (RUPTURE)

IX, WHAT IS FRACTURE MECHANICS?

- UNDERSTANDING OF DUCTILITY
- TOOL TO ASSESS TOLERABLE SIZES OF DEFECTS

X. WHAT'S INVOLVED IN **FR.** M.?

1. STRESS ANALYSIS
2. DEFECT ANALYSIS
3. MATERIAL ANALYSIS
4. ENVIRONMENT ANALYSIS

XI. WHAT DETERMINES WHICH FR. M. PRINCIPLE IS TO BE USED?

- THE FRACTURE MODE $\longrightarrow$ JUDGED BY

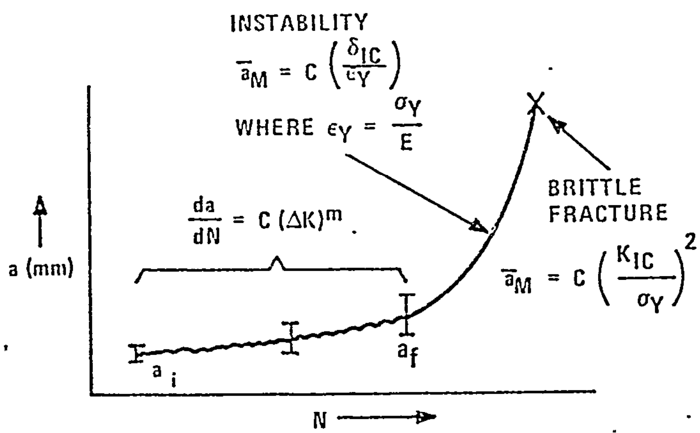
  1. OPERATING STRESSES (LEVEL).
  2. STRESS TYPE.
  3. GEOMETRY.
  4. ENVIRONMENT.
  5. MATERIAL PROPERTIES.
  6. STRAIN RATE.

XII. WHAT ARE THE PRINCIPAL FR. M. PRINCIPLES?

1. LEFM $\rightarrow K_{Ic}$ $\longrightarrow$ BRITTLE FRACTURE
2. COD $\rightarrow \delta_{IC}$ (UK)
3. J-INTEGRAL $\longrightarrow J_{Ic}$ (USA)

$\left.\begin{array}{l}\text{2. COD} \rightarrow \delta_{IC} \text{ (UK)} \\ \text{3. J-INTEGRAL} \longrightarrow J_{Ic} \text{ (USA)}\end{array}\right\}$ GENERAL YIELD

4. $\frac{da}{dN} = C(\Delta K)^m$ $\longrightarrow$ FATIGUE FAILURE



$\bar{a}_M$ = TOLERABLE (ALLOWABLE) DEFECT PARAMETER WHICH MUST BE LESS THAN a_C.

$K_{IC} = (E\ J_{IC})^{1/2}$

$\delta_{IC} = \frac{J_{IC}}{m\sigma_Y}$

Graphical illustrations of fatigue failure mode from an incipient discontinuity (Plot of discontinuity size versus endurance).

XIII. CHARACTERIZATION OF FATIGUE FROM A FRACTURE MECHANICS POINT OF VIEW MEANS

1. SAFETY FROM CATASTROPHIC FAILURE,

2. LARGER SIZE DISCONTINUITY PERMISSIBLE,

3. UTILIZATION OF CYCLIC STRESS RANGE,

4. DISCONTINUITY DIMENSIONING, LOCATION AND INTERACTION THEREOF,

5. DETERMINATION OF CRACK PROPAGATION RATE,

6. ESTABLISHMENT OF LIMIT TO CRACK PROPAGATION,

7. SELECTION OF CONFIDENCE LEVEL,

8. QUALITY CATEGORIZATION,

9. ENVIRONMENTAL CONSIDERATIONS,

XIV. HOW DOES NDE RELATE TO FR. "M,?

1. WELD DEFECTS CONSTITUTE CENTER OF NDE.

2. DIMENSIONING.

3. DETECTION,

XV. CRITIQUE OF FR. M.

(A) ACCURACY $\rightarrow$ F (NDE, STRESSES, TEST METHOD),

(B) NO GUARANTEE OF DEFECTS PRESENT ELSEWHERE,

(c) NO TELLING LEVEL OF CONFORMITY TO SPECIFICATIONS,

(D) 100% CONFIDENCE $\leftrightarrow$ 100% I INSPECTION OR ENHANCEMENT BY OTHER MEANS,

(E) NO ASSURANCE OF CONFIDENCE FROM SHIP TO SHIP,

(F) DISPARITY BETWEEN ARTIFICIAL AND GENERIC DEFECT ASSESSMENT. AND DIFF. MODELS $\rightarrow$ DIFF. RESULTS,

(G) DIFFICULTY IN DEFINING EXACT AMBIENT CONDITIONS (TEMPERATURE, SALINITY, ETC.)

XVI. CAUSES OF SHIP FAILURES

- FAILURES ARE NOT MONOPOLIZED BY A SINGLE CAUSE.

- MULTITUDE OF CAUSES,

- DOMINANT CAUSES OF FATIGUE:

  - STRUCTURAL DESIGN DETAILS

  - MISALIGNMENTS

- WELD DEFECTS RANK VERY LOW AS AN EXCLUSIVE CAUSE OF "CRACKING",

- RATIO OF ALL REPORTED CAUSES COMBINED TO WELD DISCONTINUITIES IS ~ 6:1.

XVII. (A) <u>AVAILABLE STATISTICAL DATA</u>

- TYPICALLY LESS THAN 5% OF A COMMERCIAL SHIP IS INSPECTED,

- AMOUNT OF WELD REPAIR (W.R.) DONE IN A GIVEN SHIPYARD CAN BE LOOKED AT IN DIFFERENT WAYS:

  1. W. R. IN SHOP,
  2. W. R. ON SHIPWAYS.
  3. W. R. DUE TO WELD DEFECTS EXCLUSIVELY,
  4. W. R. DUE TO WELD DEFECTS, POOR FIT UP, "COSMETIC" REASONS,
  5. W. R. ACCORDING TO WELD PROCESS USED.
  6. W. R. AS PER LINEAR FEET INSPECTED,
  7. W. R. OWING TO RANDOM OCCURENCE OF WELD DISCONTINUITIES.
  8. W. R. ACCORDING TO CODES OR OTHER REQUIREMENTS,
  9. W. R. STRICTLY IN TERMS OF FR. M. CRITERION,

XVII. (B) DATA (CONTINUED)

- OCCURRENCE OF DEFECT TYPES DEPENDS ON:

  1. WELD PROCESS USED
  2. INSPECTION METHOD APPLIED
  3. TYPE OF WELD MADE
  4. JOINT FIT UP

- RANKING OF WELD DISCONTINUITIES

  DETECTION BY RADIOGRAPHY

(A) AS PER PROCESS:

MANUAL WELDING	AUTOMATIC WELDING
1. SLAG	1. LOP
2. POROSITY	2. CRACK
3. LOP, LOF	3. POROSITY
4. CRACK	4. SLAG

(B) AS PER LINEAR FEET

1. SLAG
2. LOP
3. LOF
4. POROSITY

(c) AS PER RANDOM OCCURRENCE

1. SLAG
2. POROSITY
3. LOP
4. LOF

DETECTION BY VISUAL INSPECTION

ORDER OF IMPORTANCE OF DEFECTS

1. UNDERCUT IN FILLET WELDS

2. SURFACE POROSITY

3. UNDESIRABLE BEAD CONTOUR (WELD PROFILE)

4. CRACKS AT WELD CRATERS

TOTAL AMOUNT OF WELD REPAIR ACCORDING TO BOTH X-RAY AND VISUAL INSPECTION:

11-14%

DUE MOSTLY TO:

1. SLAG INCLUSIONS

2. LOP, LOF

3. POROSITY

4. UNDERCUT

5. CRACKS

XVIII. COST OF WELD REPAIR

- DEPENDS ON MANY FACTORS
- KNOWN TO BE AS HIGH AS $1.00 MILLION PER SHIP (E.G. LARGE TANKER) WITHOUT OVERHEAD (I.E., DIRECT COST).
- HALF OF THIS AMOUNT COULD BE SAVED THROUGH:

1. IMPROVEMENTS IN DESIGN DETAILS,
2. COMPREHENSIVE Q.C. SYSTEMS APPROACH.
3. ELIMINATION OF UNNECESSARY WELD REPAIR,
4. APPLICATION OF FR. M. TO WELD ACCEPTANCE STANDARDS,
5. SUBSTITUTION OF SMA WITH AUTOMATIC WELDING PROCESSES,
6. INTRODUCTION OF ADVANCED FABRICATION TECHNOLOGY TO ENHANCE JOINT FIT UP,
7. EDUCATION AND TRAINING,

SUMMARY

- DEFECTS ARE NOT ALWAYS HARMFUL,
- WELD REPAIR COULD BE MORE DELETERIOUS,
- DIFFERENT DEFECTS, THEIR SIGNIFICANCE IS INFLUENCED BY SEVERAL FACTORS,
- FR. M. REQUIRES STRESS, DEFECT, MATERIAL TOUGHNESS DETERMINATION AND ENVIRONMENT IN CASE OF FATIGUE,
- PURPOSE OF DEFECT TOLERANCE STUDY IS TO AVOID UNNECESSARY REPAIR, DEGRADATION, "FITNESS FOR PURPOSE",
- THERE ARE SEVERAL FAILURE MODES: IN SHIPS → FATIGUE IS PREDOMINANT,
- FR. M. IS CRITICALLY DEPENDENT ON NDE.
- FR. M. RELATES ONLY TO INSPECTED WELDMENT.
- FR. M. IS RELIABLE AND SHOULD BE ACCEPTED IN CODES FOR SHIPBUILDING,
- SHIP FAILURES ARISE FROM MANY CAUSES,
- RANKING OF WELD DEFECTS DEPEND ON SEVERAL FACTORS,
- RANGE OF WELD REPAIR AMOUNT 11-14%
- ONE HALF OF WELD REPAIR EXPENDITURES COULD BE SAVED,
- FORMATION OF TASK FORCE,
- IMPLEMENTATION OF "QC SYSTEMS LOOP",
- CLEAN UP DESIGN DETAILS, DECREASE JOINT MISALIGNMENT AND IMPROVE FABRICATION TECHNOLOGY,
- WELD DISCONTINUITIES AS SOLE CAUSE OF FAILURES IN SURFACE VESSELS HAVE LOW RANKING COMPARED TO OTHER CAUSES,
- COMPREHENSIVE QUALITY CONTROL AWARENESS THROUGH CONSTANT EDUCATION,

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